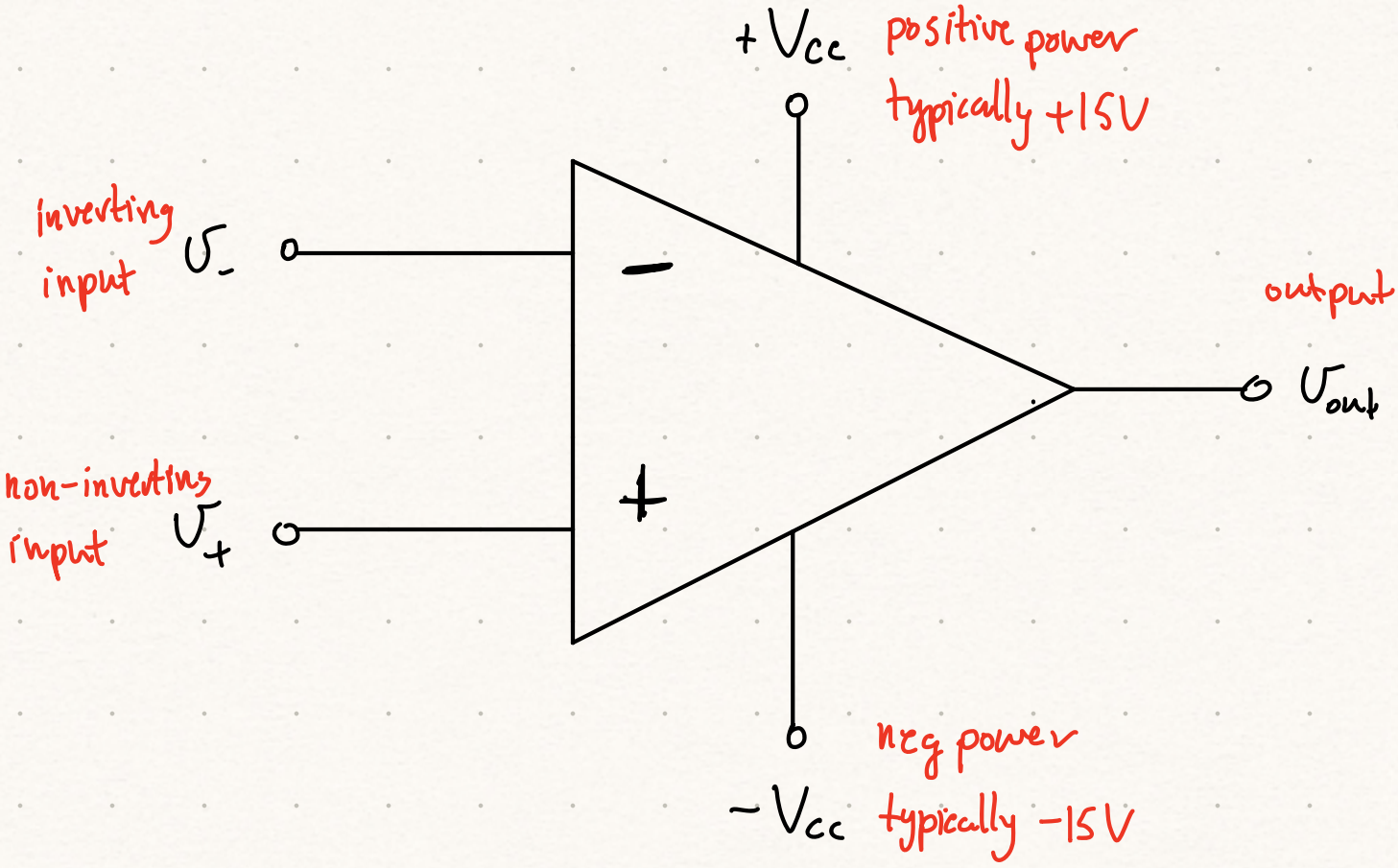
PHYS 231

Oct. 15, 2025

Today Operational Amplifiers (Op Amps)

An op amp is a device w/ :

- two inputs (v_-, v_+)
- one output (v_{out})
- two power terminals ($+V_{cc}$, $-V_{cc}$)



$+V_{cc}$ must be a positive constant (DC) voltage (+15V)

$-V_{cc}$ must be a negative constant (DC) voltage (-15V)

v_-, v_+ : the inverting & non-inverting inputs can be positive or negative fcns of time.

Treat the op amp as a black-box device that performs the following operation:

$$v_{out} = A_{OL}(v_+ - v_-)$$

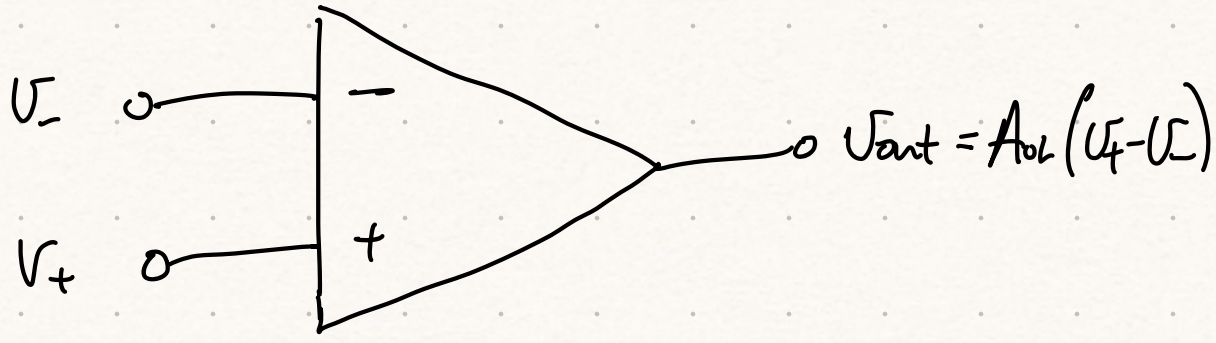
A_{OL}: "open loop" gain.

no feedback from output to inputs.

In the lab we will use LM741 op amp & it is designed to have an open loop gain of about:

$$A_{OL} \approx 2 \times 10^5 = 200,000 \text{ (large)}.$$

In circuit diagrams, the power terminals $\pm V_{cc}$ are often omitted for clarity. However, the op amp always needs to be powered to fun properly.



Op amp limitation:

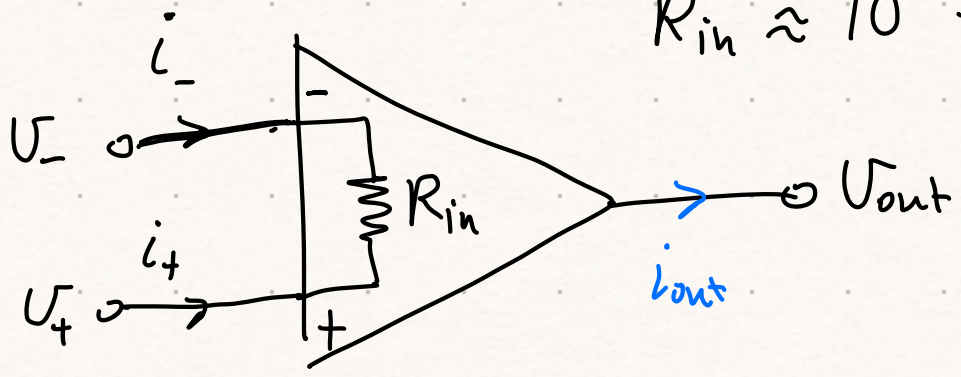
saturation (max/min) voltage

① $|V_{out}| \leq V_{sat} \approx V_{cc} - 1$

If $V_{cc} = 15\,V$, then $V_{sat} \approx 14\,V$.

Another characteristic of the op amp is that it have very large input resistance.

$R_{in} \approx 10^{12} - 10^{15}\ \Omega$



The large input resistance limits the current i_- & i_+ into op amp inputs. Usually ignore i_- & i_+ s.t. $i_- \approx i_+ \approx 0$.

If we assume $R_{in} \to \infty$, then $i_- \approx i_+ \approx 0$

$\Rightarrow$ no current into or out of the op amp inputs.

Note that the current at the output i_{out} does <u>not</u> have to zero.

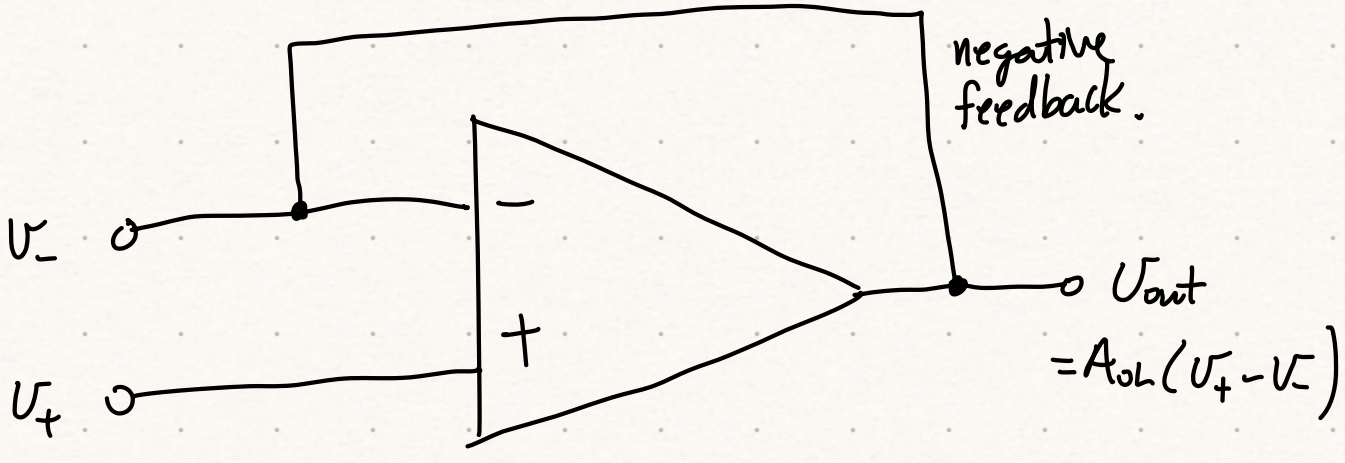
Op Amp Golden Rules

1. Op Amp input resistance $\rightarrow \infty$

$$i_- = i_+ = 0$$

no current into or out of op amp inputs

2. The second golden rule applies to op amps using negative feedback.



Know $V_{out} = A_{OL}(V_+ - V_-)$.

With our negative feedback, we require:

$$V_{out} = V_-$$

$$\therefore V_- = A_{OL}(V_+ - V_-) \quad \text{solve for } V_-.$$

$$V_- + A_{OL} V_- = A_{OL} V_+$$

$$\therefore V_-(A_{OL}+1) = A_{OL} V_+$$

$$\therefore V_- = \left(\frac{A_{OL}}{A_{OL}+1}\right) V_+$$

If $A_{OL} \gg 1$ (as it always is),

then $\frac{A_{OL}}{A_{OL}+1} \simeq 1$ s.t. $\boxed{V_- = V_+}$

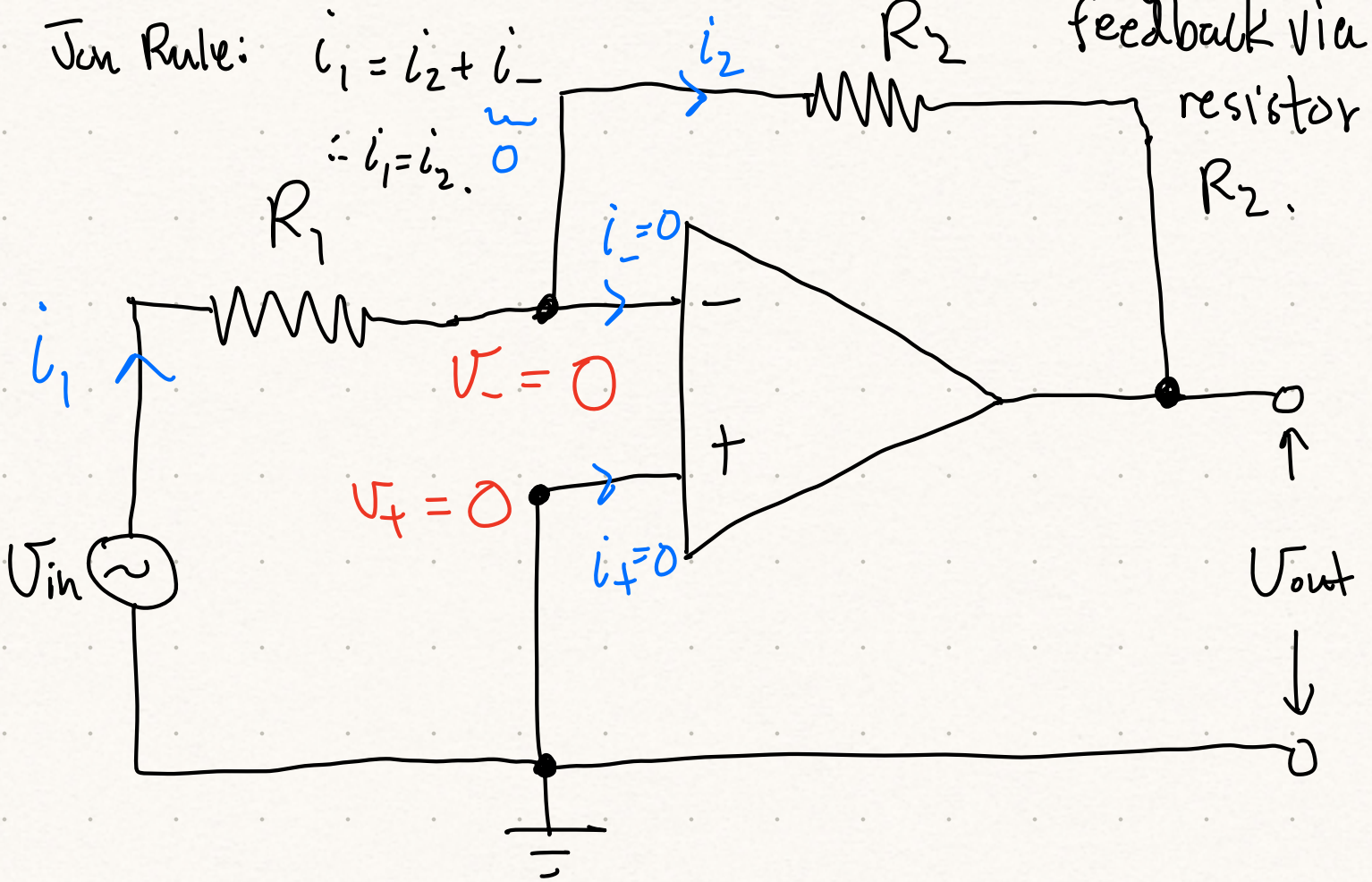
2nd Golden Rule:

When using negative feedback.

$$V_+ = V_-$$

First op amp application (Lab #5)

Inverting amplifier



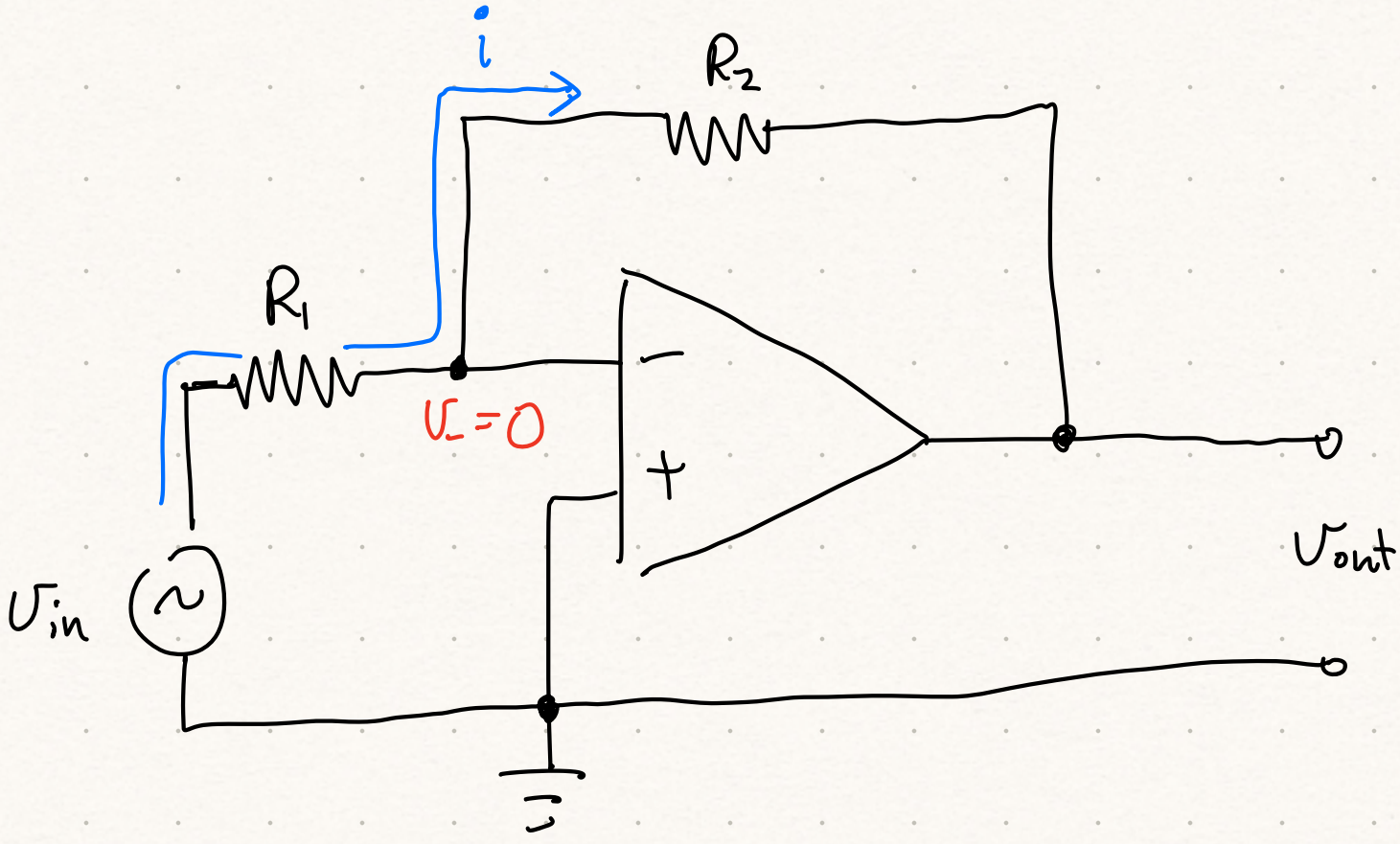
- non-inverting input is connected directly to gnd. $\therefore V_+ = 0$.
- if using negative feedback ✓, then by Golden Rule #2, $V_+ = V_- = 0$.

Golden Rule #1. $i_- = i_+ = 0$

Results in $i_1 = i_2 \equiv i$

Golden Rule #2 $V_- = V_+$

since $V_+ = 0$, we have $V_- = V_+ = 0$



① Track changes in volt. from gnd to V_-

$$0 + V_{in} - iR_1 = \underbrace{V_-}_{0} \Rightarrow \boxed{i = \frac{V_{in}}{R_1}}$$

(2) Track changes in volt. from V_- to V_{out}

$$V_- - iR_2 = V_{out}$$

$V_- = 0$

$$\therefore V_{out} = -iR_2 = -\left(\frac{V_{in}}{R_1}\right)R_2$$

$$\therefore V_{out} = -\frac{R_2}{R_1} V_{in}$$

inverting.

Gain of amplifier is set by the resistor ratio.